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VIBRATION LEVELS IN ARMY HELICOPTERS--MEASUREMENT RECOMMENDATIONS AND DATA

By

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20. ABSTRACT

We reviewed literature on vibration levels found in currently fielded helicopters in order to prepare a comparative summary of vibration exposure levels at crew stations and of the test methods used to measure these levels. This effort was initiated at the request of the Air Standarization Coordinating Committee (ASCC) Working Party 61 and because of the wide variety of methods used in data capture and instrumentation documentation.

Sources of the literature reviewed included technical reports of U. S. Government agencies and papers in open literature. Articles were reviewed based upon three criteria: (1) quantitative description of vibration in currently fielded U. S. Army rotary winged aircraft, (2) article contents are unclassified and available for publication in open literature, (3) article describes human exposure levels of aircraft vibration.

The results of this review are in the form of abstracts of ten articles that met the criteria. Graphic data excerpted from these papers were combined to form 8 graphs from which to make comparisons and conclusions.

In addition to providing summary abstracts and data, we have written a critique of vibration test methods. We have suggested some guidelines for measuring vibration and for presenting the resulting data, placing emphasis on documentation of test methods and instrumentation.

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INTRODUCTION

This report is a comparative summary of vibration exposure levels at crew stations in currently fielded Army rotary wing aircraft and the test methods used to measure these levels. The report was written at the request of the Air Standardization Coordinating Committee (ASCC) Working Party 61*. The ASCC requested a summary of vibration exposure levels at crew stations of currently fielded US Army helicopters. We excerpted these data from existing technical documents, condensed them into graphical form, and present them in eight figures.

In addition to the summary data, we have written a critique of vibration test methods based upon the literature which we reviewed. This critique is the central theme of our discussion. In the process of compiling vibration data, we encountered considerable difficulty. Data on vibration were presented in a plethora of different formats, in a wide variety of units, and with varying degrees of instrumentation documentation. This nonuniformity of data reporting hampered consolidation and comparison of the vibration information. We have suggested some guidelines for measuring vibration and for presenting the resulting data. We have placed great emphasis on the documentation of test methods and instrumentation. We hope that this document will be of assistance to military and civilian agencies alike in bringing some standardization to the measurement of vehicle vibration.

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*Department of the Air Force (SGES), 9 Jan 80, ltr to USAARL, Items for US Project Officers, ASCC Working Party 61. Located in HQ, USAARL.

METHODS AND MATERIALS

The literature search on vibration in current US Army rotary wing aircraft included both technical reports of US Government agencies and papers in the open literature. Of the hundreds of citations we reviewed, ten were chosen for comparison based upon the following criteria:

a. Article describes, quantitatively, vibration levels in <u>currently</u> fielded US Army rotary wing aircraft.

b. Article contents are unclassified and available for publication in open literature.

c. Article describes levels of exposure of humans to aircraft vibration.

For each of the selected articles, we have written an abstract which appears in the LITERATURE CITED section. In each abstract we answered the following questions:

a. What aircraft was studied?

b. Where were vibration measurements taken?

c. What instrumentation was used?

d. What are the measurement limitations on the data?

e. How does the data relate to current vibration standards or specifications?

Where appropriate, we excerpted graphical data from the abstracted paper and combined these data with similar data from other sources to provide the reader with a useful means for comparison. In all cases, we have scaled the original data to express vibration acceleration in metric units (m/s^2) using the conversion $1g = 9.8\ m/s^2$.

LITERATURE CITED

Laing, E. J. 1974. Army helicopter vibration survey methods and results. *J. American Helicopter Society.* 19(3):28-38.

In this methods paper, Laing details the procedure which he used to acquire and analyze helicopter vibration data. We have not reproduced data from this paper since it would duplicate data excerpted from other sources which are cited. Laing compares vibrations in various aircraft and delineates sources of vibrations due to mechanical devices in the aircraft. He addresses the adequacy of vibration isolation and compares avionics vibration to the applicable military standard, MIL-STD-810B. He summarizes pilot and seat pad transmissibility in the CH-54B and the UH-1H and compares crew station vibration in these aircraft to limits established in MIL-H-8501A.

Laing, E. J., Claxton, J. D., Graham, W. A., Jr., and Hepler, L. J. 1972. *Instrument panel and avionics compartment environmental survey production OH-58A helicopter.* Edwards Air Force Base, CA: United States Army Aviation Systems Test Activity. USAASTA Project No. 70-15-1. AD 907738.

This is Laing's first publication of a series of aircraft vibration and temperature surveys. The aircraft under study is the OH-58A (Kiowa), a two-bladed, single-rotor, observation helicopter. Vibration measurements are made at seven locations under 29-flight conditions. Mounting sites include five on the instrument panel and two in the avionics compartment. No human vibration data are taken. Endevco* piezoelectric accelerometers (models 2224C, 2211C, 2235C, and 2223C) are used in conjunction with Endevco* model 2640 and 2632-N1 charge amplifiers. We include this reference since it does provide some background information relevant to the work by Laing (1974).

Laing, E. J., Hepler, L. J., and Merrill, R. K. 1973. *Vibration and temperature survey production UH-1H helicopter.* Edwards Air Force Base, CA: US Army Aviation Systems Test Activity. USAASTA Project No. 70-15-2. AD 909441.

*Endevco Corporation, San Juan Capistrono, California

Laing describes a study of temperature and vibration in the UH-1H (Huey-Iroquois) two-bladed, single-rotor, utility helicopter. Vibration measurements are made at 49 locations during a total of 55-flight conditions. Of these, the following locations are associated with the pilot: seat pad, seat structure, pilot foot rest, thrust control grip, cyclic grip, pilot helmet (SPH-4) and bite block. Instrumentation includes Endevco* triaxial accelerometers models 2228C or 2223C and single axis accelerometers 2226C or 2242C with MP Electronics† model 9402216 line drivers and amplifiers. Overall system bandwidth is estimated at 3-200 Hz with an amplitude accuracy of ± 10%. Twelve data channels are FM multiplexed onto two tape recorder channels. A switching circuit is used to select between 8 sets of 12 channels each for a total of 96 channels.

Laing analyzes the data using a Spectral Dynamics§ 301B real-time analyzer in conjunction with a model 302B ensemble averager. The analysis bandwidth is 2000 Hz. The ensemble average includes 8 seconds of data (2 seconds during maneuvering). Data are "compressed" by calculating the mean, standard deviation (SD) and maximum at each frequency for several related axes and accelerometer locations. Laing presents the resulting "compressed" data graphically as plots of acceleration amplitude in g's versus frequency. In addition to mean amplitude, mean plus three standard deviation data are also plotted. This is the level below which 99.87% of all acceleration values lie. In addition to the compressed vibration spectra, Laing presents transmissibility factors for vibration isolators and for the pilot. Pilot transmissibility is the ratio of the acceleration measured at the bite bar to the combined acceleration from all sources of vibration input to the pilot. Data from this report are reproduced in Figures 1, 2, and 4. A discussion of these and all figures is also included in the RESULTS AND DISCUSSION section. Laing compares this data with MIL-STD-801B and MIL-H-8501A.

Laing, E. J., Merrill, R. K., and Reid, J. S. 1973. *Vibration and temperature survey CH-54B helicopter.* Edwards Air Force Base, CA: US Army Aviation Systems Test Activity. USAASTA Project No. 70-15-3. AD 910495.

The authors subject the CH-54B six-bladed, single-rotor, cargo helicopter to a test protocol similar to that previously carried out by Laing, Hepler, and Merrill, 1973. Instrumentation analysis and reporting methods are the same. Selected data from this report are reproduced in Figures 1, 2, and 4. Laing compares his test results with MIL-STD-810B and MIL-H-8501A.

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*Endevco Corporation, San Juan Capistrono, California

†MB Electronics, cited by Laing. No other information was available on this manufacturer at the present time.

§Spectral Dynamics Corporation, San Diego, California

Laing, E. J., Smith, J. R., and Hill, C. 1973. *Vibration temperature survey production OH-6A helicopter.* Edwards Air Force Base, CA: US Army Aviation Systems Test Activity. USASTA Project No. 70-15-4. AD 914172L.

The authors subject the OH-6A four-bladed, single-rotor, observation helicopter to a test protocol very similar to the one previously carried out by Laing, Hepler, and Merrill, 1973. Instrumentation analysis and reporting methods are the same. Selected data from this report are reproduced in Figures 1, 3, and 4. Laing presents comparisons of his data with MIL-STD-810B and MIL-H-8501A.

Laing, E. J., and Weand, A. E., Jr. 1974. *Vibration and temperature survey production AH-1G helicopter.* Edward Air Force Base, CA: US Army Aviation Systems Test Activity. USAASTA Project No. 70-15-5. AD A002063.

Laing subjects the AH-1G (Cobra) two-bladed, single-rotor, attack helicopter to a protocol very similar to the protocol previously carried out by Laing, Hepler, and Merrill, 1973. Instrumentation analysis and reporting methods are the same. Selected data from this report are reproduced in Figures 1, 3, and 4. Laing presents comparisons of his data with MIL-STD-810B and MIL-H-8501A.

Laing, E. J., Hawley, M. A., Smith, R. B., O'Connor, J. C., and Kronenberger, L., Jr. 1975. *Vibration and temperature survey production CH-47C helicopter.* Edwards Air Force Base, CA: US Army Aviation Engineering Flight Activity. USAAEFA Project No. 70-15-6. AD A022348.

Laing subjects the CH-47C (Chinook) three-bladed, two-rotor, cargo helicopter to a protocol very similar to the protocol previously carcied out by Laing, Hepler, and Merrill, 1973. Instrumentation analysis and reporting methods are the same. Selected data from this report are reproduced in Figures 1, 2, and 4. Laing presented comparisons of his data with MIL-STD-810B and MIL-H-8501A.

Hutchins, C. W. 1972. *Measurement of triaxial vibration levels at significant human interface points on the CH-47C and SH-3A helicopters.* Warminister, PA: Naval Air Development Center. JANAIR Report 721122. AD 761199.

LCDR Hutchins describes measurements of aircraft vibration which he made in the CH-47C (Chinook) three-bladed, two-rotor, cargo helicopter and in the Navy SH-3A helicopter. Triaxial acceleration measurements are taken at the rudder pedal, collective control stick, instrument panel,

and pilot's seat. The pilot's head acceleration is measured only in the vertical axis. Statham* A52 and A6 strain gauge accelerometers are mounted in a box approximately 6 cm by 3 cm by 1.5 cm which also contained signal conditioning electronics and batteries. The box is then attached to the measurement site. The mouth-mounted bite bar accelerometer has electronics mounted at a distance from the accelerometers. Hutchins uses FM multiplexing of the acceleration signals to record all vibration data on two channels of a Hewlett Packard† 3960 tape recorder.

Hutchins analyzes the resulting data over the frequency range 0-30 Hz using a General Radio§ model 1925 third octave multifilter. For each flight condition, two 60-second blocks of data are analyzed. Both values are graphed to indicate the reproducibility in the data. A sine wave (equivalent to $\pm$ 1g = 9.8 m/s^2) in the recorded signal is used to calibrate the third octave filter in order to insure comparability between channels. Major peaks appearing in the third octave analysis are investigated in more detail by analyzing the data with a tenth octave multifilter. Results of the tenth octave and third octave analysis are presented in tabular form for each maneuver, accelerometer position, and aircraft type. Data with the pilot in contact with controls are compared to data with the pilot not in contact with the controls. Hutchins does not refer to or suggest any standards for vibration measurement or exposure. Selected spectrograms from Hutchins' paper are reproduced as Figures 5 and 6 for the CH-47C aircraft.

Mittag, C. F., Natata, J. I., Coumatos, M. J., Skinner, G. L. Kowley, S., Meiss, J. C., Buckanin, R. M. 1976. *Government competitive test utility tactical transport aircraft systems (UTTAS) Sikorsky YUH-60A helicopter.* Edwards Air Force Base, CA: US Army Aviation Engineering Flight Activity, USAAEFA Project No. 74-06-1. Limited distribution#.

Mittag describes the Government Competitive Test of the YUH-60A helicopter (Blackhawk/UTTAS) of which vibration measurements are a part. Vibration recordings are made at 15 locations including the seat of the pilot and copilot, right hand shroud of the cockpit instrument panel, cabin floor, center of gravity of the aircraft, cyclic control, heel rest and left pedal. Instrumentation used to gather the data is not reported. The data are analyzed using a Spectral Dynamics** real-time spectral analyzer, model 301B, in conjunction with a Spectral Dynamics Corp., model 302B ensemble averager.

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*Gould, Inc., Measurement Systems Div., 2230 Statham Blvd, Oxnard, CA.
†Hewlett Packard Corporation, Palo Alto, CA.
§General Radio, GenRad Inc., Concord, MA.
Data from this report were cleared for release by HQ, US Army Aviation Systems Command, DRDAV-DI (Letter to USAARL), 1 Aug 80, subj: Request for Vibration Information. Located in BAR Division, USAARL.
**Spectral Dynamics Corporation, San Diego, CA.

Resolution of the data is 0.2 Hz for the 100 Hz analysis range and 1 Hz for the 500 Hz range. Eight seconds of data are averaged to provide the final spectrum. Only the 17.2 Hz (4/rev) main rotor frequency component of the vibration is reported. All acceleration values are reported in single amplitude g's. The main rotor 4/rev vibration component along each of three linear orthogonal axes is plotted as a function of calibrated airspeed, rotor RPM, true airspeed, and load factor for several flight profiles. No reference is made to general vibration standards. Data from the Mittag study are reproduced in Figure 7. Vibration data are compared to the "Prime Item Development Specification for the Utility Tactical Transport Aircraft System", Specification No. AMC-CP-2222-S1000, 1 March 1976.

> Dupis, H. 1978. Human exposure to mechanical vibration at lying posture in the ambulance helicopter UH-1D. In: Knapp, S. C., *Operational helicopter aviation medicine:* Aerospace Medical Panel's Specialists' Meeting, 1978, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. p.12-1-12-11. AGARD-CP-255.

Dr. Dupuis records and analyzes vibration data in a UH-1D helicopter equipped as an air ambulance. Acceleration measurements are made at the heel, pelvis, shoulder blade, and head of a volunteer subject lying on a stretcher. Additional measurements are made at the abdominal wall, at the forehead of the subject and at the fastening point of the stretcher to the aircraft mount. The measurements are duplicated at three stretcher locations: lower, middle, and upper positions. The instrumentation system used to record the vibration includes strain gauge accelerometers having a range of $\pm$ 100 m/s^2 and a natural frequency of 250 Hz. Vibrations are recorded for each flight condition, stretcher condition, and acceleration axis using a FM multiplex system and a FM tape recorder. Vibration acceleration values are reported as a root mean square average. Strip chart samples of acceleration under selected conditions and spectra for selected accelerations are presented. Exposure tolerance curves for a lying posture are given. Significant frequency peaks are discovered at 5 to 10 Hz and at 30 to 50 Hz. Data from Dupuis' study are reproduced in Figure 8. Exposure values presented by Dupuis are taken, in part, from German Standard VDI 2057, "Beurtheilung der Einwirkung mechanischer Schwingunger auf den Menschen," Oktober 1963, Februar 1975, January 1976.

RESULTS AND DISCUSSION

In discussing the data which are presented in this report, we address three general points:

a. What information does the cited data present concerning the level of vibration imparted to crewmen?

b. How do the standards referenced by each author affect usefulness of the collected data for human factor analysis?

c. What lessons can we learn from the methods used by these investigators to acquire, analyze, and present their data?

The Laing data represents the most general and complete set of vibration data available on US Army helicopters. The data which relates to crew vibration exposure are presented in Figure 1 (p. 22). We have organized Laing's data into two generic groups for analysis. The first is the cargo and utility helicopter group and the second is the attack and observation helicopter group. For each aircraft, Laing presents crew station vibration subdivided into two flight condition groups: (1) takeoff, landing, and maneuvering, and (2) hover, level flight, climb and descent. We have retained this grouping in the figures. From Laing's data it is apparent that the level flight condition group experiences less vibratory stress than the maneuvering condition group. Comparing the magnitude of the aircraft vibration within the cargo/utility group, we find that the CH-47C, UH-1H, and the CH-54B have different vibration profiles. The vibration in the CH-47C is the most severe while vibration in the CH-54B is least severe. Insufficient data are available within the attack/observation group for meaningful comparison.

Seat pad transmissibility for each aircraft, as measured by Laing, is summarized in Figures 2 (p. 23) and 3 (p. 24). Seat pad transmissibility is the ratio of the acceleration of the junction of the pilot's buttocks and the surface of the seat pad as measured by an instrumented metal plate inserted at the interface. The "seat pad" is simply the surface of the seat on which the pilot sits. It may be a cushion or a tightly stretched cloth netting depending upon aircraft type, model, and modification. Beginning in the attack/observation group (Fig 3), we find that the AH-1G aircraft seat pad transmissibility is plotted for two conditions: weapons firing and nonweapons firing. The nonweapons firing data are plotted only to 216 Hz. Beyond this frequency insufficient vibration was measured to allow the plotting of higher frequency transmissibility terms. During weapons firing, vibration amplitude increased significantly across the entire spectrum. Higher frequency vibration was produced in the airframe at a level sufficient to allow measurement of the transmissibility terms up to about 800 Hz. In the low frequency range, the weapons firing values do not differ radically from the nonweapon firing values.

The OH-6A seat demonstrates a much lower transmission of vibration than the AH-1 seat. The exact cause for this is unknown and cannot be determined from the data available in the original report.

Transmissibility of the seat pads in the cargo/utility group (Fig 2) differs widely both in magnitude and shape. The CH-47C is equipped with a seat cushion rather than the tight cloth webbing found in the UH-1H. By contrast the CH-54B has a solid cushion seat unique to that aircraft. These seat differences may contribute to the exceptionally large difference between seat pad transmissibilities of these aircraft. Vibration at frequencies above 100 Hz must have been rapidly attenuated by the seat or were very small at the seat structural mount; values of transmissibility much beyond 100 Hz are not reported.

Seat pad transmissibility (T_S) varies widely between the aircraft listed. Factors which may influence this variation are: The anthropometry of the aviator in the seat during the measurements, type of seat structure, construction and composition of the "seat pad" as well as age and maintenance condition of the seat. Many of these factors are extremely difficult to quantify and, thus, are not reported. For this reason, some caution should be exercised in interpreting differences in the data. You observe that amplification ($T_S > 1$) of vibration by seat pads occurs in all of the seats and aircraft tested with the notable exception of the OH-6A aircraft. These amplifications occur below 100 Hz.

Pilot transmissibility (T_p) is defined by Laing as the ratio of the pilot's bite block acceleration to the combined right pedal, collective, cyclic, seat frame and seat pad accelerations. The same caution directed toward interpretation of the seat pad transmissibility data applies to the pilot transmissibility data as shown in Figure 4 (p. 25). In addition to the variables which affect seat pad transmissibility, factors such as posture and muscle tension of the pilot may contribute to data variation (Griffin, 1975). In the attack helicopter, there is a large difference between transmissibility as measured in the weapons firing and nonfiring conditions. No reason for this is mentioned in the original report. Based on the myriad possible causes for this difference, we will not attempt an explanation. The OH-6A has a fundamental vibration of 32 Hz. Therefore, there is insufficient vibrational input to the pilot to plot the transmissibility below that point. The cargo/utility group of aircraft show the characteristically steep dropoff of pilot transmissibility with frequency. This is in general agreement with other determinations of transmissibility done by Griffin in 1975.

Two military test and evaluation documents are referenced by Laing in his work. These are MIL-H-8501A, "Helicopter flying and ground handling qualities; general requirements for" (DOD 1962), and MIL-STD-810B, "Envi-romental test methods" (DOD 1967). The latter standard describes the material tests that include a vibration tolerance test to which hardware is exposed prior to use in military vehicles. The standard is in no way related to the human vibration exposure data. Military specification 8501A

does provide limited guidelines for vibration at crew station and controls of military helicopters. The standard offers no guidance on appropriate instrumentation for measurement or techniques for analysis of the resulting data. This is a significant shortcoming since considerable variation may be introduced into the resulting vibration data by differences in analysis technique. Possible analysis methods may include: third octave, narrow band, wide band, peak determination, etc. For a discussion of various vibration descriptors see Jex (1980). Due to a lack of analysis mode definition in the standard, comparisons of vibration data with MIL-STD-8501A are open to much interpretation.

Since the completion of Laing's work, the International Organization for Standardization (ISO) has published a standard, ISO 2631-1974, "Guide for the evaluation of human exposure to whole body vibration" (ISO, 1974). Although the limits set by the standard have been subjected to discussion and criticism,* the standard specifies in detail the manner in which data may be taken, analyzed and formatted before comparisons are made. For broad band vibration, ISO 2631 requires reduction of the data by third octave band (or narrower) spectral analysis. Each spectral component is then compared to the limit specified for the center frequency of the third octave band in which it falls. The standard cautions that this assumes no interactions between discrete vibration frequency components, a condition which, at the time of publication, was undocumented by experimental results. The standard also specifies that vibration will be measured at the buttocks of the seat occupant in cases where the seat is not rigid. This, in the case of the Laing data, is equivalent to the seat pad acceleration measurement. Since Laing's analysis bandwidth is 1 Hz for the human vibration measurements, direct comparison of seat pad data with the ISO 2631 standard is appropriate between 5 Hz (third octave bandwidth of 1.2 Hz) and 80 Hz (the upper limit of the standard). Unfortunately, the seat pad acceleration is not directly available from the Laing reports. The data from Hutchins' report, Figures 5 (p. 26) and 6 (p. 27), are in the appropriate format for comparison to ISO 2631, but Hutchins measures acceleration at the seat frame. Such data do not represent the actual vibration input to the buttocks of the pilot and are not directly comparable with the ISO standard.

Dupuis presents narrow band analysis of vibration in Figure 8 (p. 29) which is in accordance with analysis methods outlined in ISO STD 2631. Both he and Laing provide summary data for discussion while still including complete spectra. This method provides us with a detailed and complete picture of the outcome of their experiments. Basic parameters of the spectral analysis are not included in Dupuis' report but are available in Dupuis and Hartung (1972).

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*The ISO member bodies of the USSR and United Kingdom express disapproval of the standard on technical grounds (ISO 1974). Cohen (1977) cites results which suggest that individual third octave band measurements may not be treated independently as the ISO standard permits.

The Mittag data in Figure 7 (p. 28) present only the 17.2 Hz component of aircraft vibration. The prime item specification (DARCOM, 1976) which Mittag used as a measurement standard in his study states that vibration levels will not exceed 0.10 g at the fundamental main rotor passage frequency. Presumably, this is why Mittag's data are presented only for the 17.2 Hz frequency.

We have learned several lessons from this literature study. Briefly stated they are:

a. Detailed documentation of all aspects of data acquisition and analysis is indispensable and should be included as an appendix to human vibration studies.

b. Where possible raw or minimally preprocessed data should be available in an appendix for use by the reader in his own specific application.

CONCLUSIONS AND RECOMMENDATIONS

The references cited in this report provide a summary of the levels of vibration to which the helicopter crewman is exposed. The graphs contained in this report give a concise and comparative summary of the various levels of vibration as reported by the cited authors. However, there is insufficient detailed vibration information to make valid comparisons between this vibration information and abundant literature which describes vibration effects under laboratory conditions. We recommend that additional field studies be conducted to complement the results of the work reviewed herein. The additional studies should be directed toward detailed measurement of head acceleration (see Jex 1980) as well as whole body acceleration. Particular attention should be given to complete documentation of the measurements in order to maximize their usefulness. Such studies will begin to bridge the gap between laboratory measurements of vibration effects and field measurements of aircraft vibration characteristics.

Reports and test results on human vibration studies should serve as a mechanism for (1) clear presentation and discussion of results for the enlightenment of the reader, and (2) detailed documentation of data, acquisition methods and analysis techniques to allow the reader to further analyze or interpret results. While this is considered good scientific practice, it is most difficult and time-consuming to effect in this area of research due to the plethora of variables which must be controlled and reported. As a minimum, we recommend that the following documentation be included in the appendix for human vibration experiments.

a. Specific instrumentation used for data acquisition and analysis (make, model).

b. Photographic documentation of transducer placement or installation (length and geometry of bite bar, orientation of sensitive axes of accelerometers).

c. Size, weight, and mode of installation of the transducers.

d. Parameters of the data acquisition system:

(1) Bandwidth (frequency range).

(2) Accuracy.

(3) Sampling rate (if digital).

(4) Aliasing filter type/cutoff/rolloff rate (if digital).

e. Parameters of the analysis system:

(1) Mathematical or statistical techniques.

(2) Block diagram or flow chart of processing protocol.

(3) Complete description of spectrum analyzer parameters to document:

(a) Analysis bandwidth.

(b) Normalization (to noise bandwidth or "per Hz").

(c) Truncating window shape (boxcar, Hanning, other).

(d) Correction for window shape.

(e) Time window length.

(f) Averages (time and number).

(g) Coherence level (for transfer function).

f. Photographic and descriptive documentation of the man-machine interface (seat, control handle, restraint mechanisms):

(1) Material properties (i.e., spring constant, damping factor, resiliency) (SAE 1962).

(2) Condition of maintenance.

(3) Setting of adjustments (seat height, collective friction, etc.).

(4) Other peculiar characteristics which may influence outcome of measurement.

g. Definition of coordinate reference system for vibration measurement. Although the acceleration reference system is usually defined as the sensitive axis of the accelerometer, it is sometimes advantageous to mathematically transform this acceleration to some other coordinate reference. For example, bite bar accelerations are frequently referenced to the center of mass of the head (Becker 1975; Jex 1980).

h. Description of volunteer subjects involved. We are not aware of any studies which specifically define the effects of individual differences on human response to vibration. We do feel from personal experience that there are significant individual differences and that documenting personal characteristics of the test subjects may be useful to investigators who in the future may wish to address human variability in dynamics response

to vibration. The following is a list of individual traits which we consider useful as documentation of the type subject population analyzed. The list is by no means exhaustive but serves as a guide. Several of these factors (1-4) are commonly documented in vibration literature (Coermann 1962; Griffin 1975; Cohen 1977).

(1) Anthropometric measurements.

(2) Weight.

(3) Physical condition.

(4) Age.

(5) Personal factors which, in the opinion of the investigator, may influence outcome of experiment.

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APPENDIX

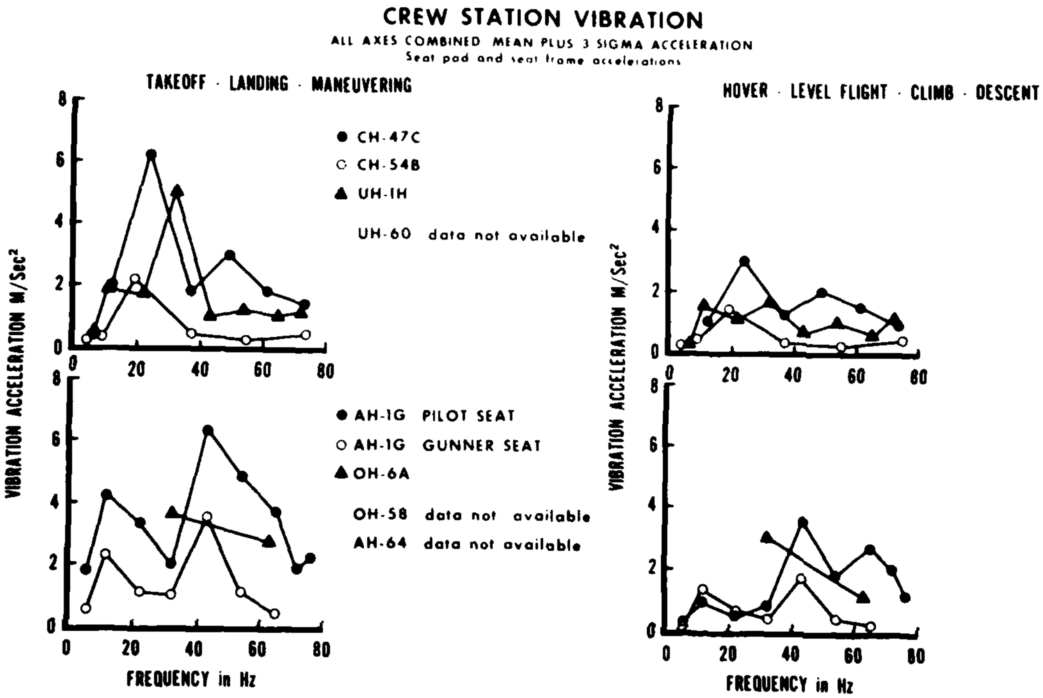

FIGURE 1. Crew Station Vibration* as Measured by Laing and Others

CH-47C	Laing (1975, p. 21)
CH-54B	Laing and Merrill (1973, p. 18)
UH-1H	Laing and Helper (1973, p. 18)
AH-1G	Pilot Seat, Laing (1974, p. 30)
AH-1G	Gunner Seat, Laing (1974, p. 30)
OH-6A	Laing and Smith (1973, p. 24)

* Original data points are shown. We have added the connecting line segments as a visual aid only. They do not indicate continuous data.

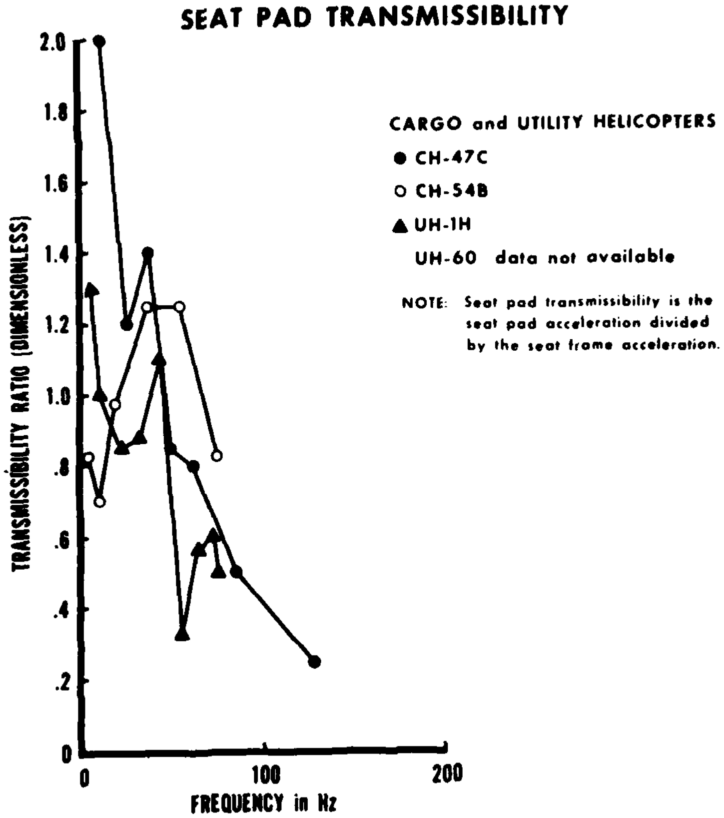

FIGURE 2. Seat Pad Transmissibility* of Cargo and Utility Helicopters Measured by Laing and Others

CH-47C	Laing (1975, p. 19)
CH-54B	Laing and Merrill (1973, p. 16)
UH-1H	Laing and Hepler (1973, p. 16)

* Original data points are shown. We have added the connecting line segments as a visual aid only. They do not indicate continuous data.

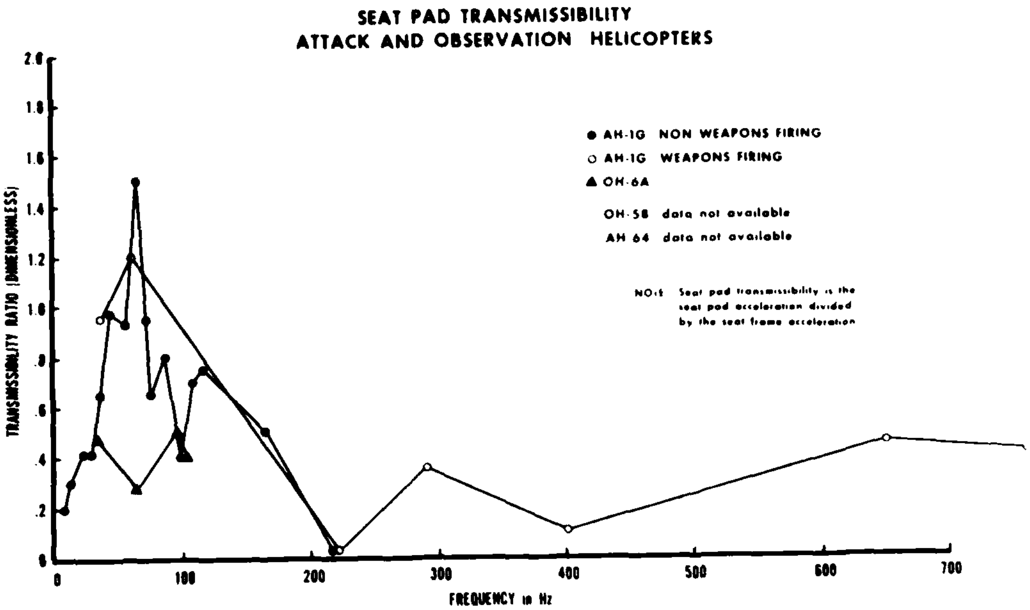

FIGURE 3. Seat Pad Transmissibility* of Attack and Observation Helicopters as Measured by Laing and Others

AH-1G Nonweapons Firing, Laing (1974, p. 27)
AH-1G Weapons Firing, Laing (1974, p. 27)
OH-6A Laing and Smith (1974, p. 23)

* Original data points are shown. We have added the connecting line segments as a visual aid only. They do not indicate continuous data.

PILOT TRANSMISSIBILITY

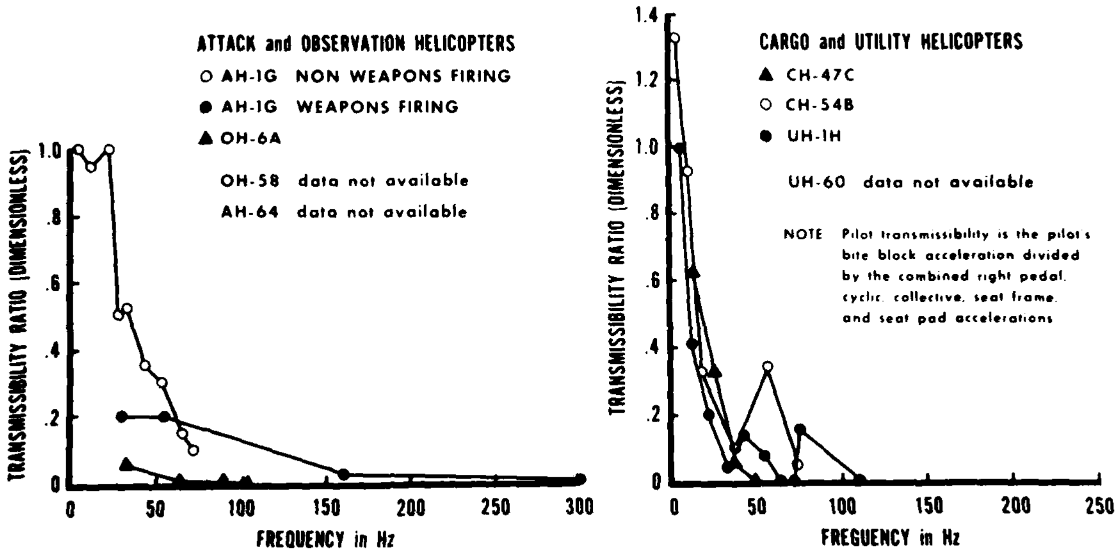

FIGURE 4. Pilot Transmissibility* as Measured by Laing and Others

AH-1G	Nonweapons Firing, Laing (1974, p. 29)
AH-1G	Weapons Firing, Laing (1974, p. 29)
OH-6A	Laing and Smith (1973, p. 23)
CH-47C	Laing (1975, p. 19)
CH-54B	Laing and Merrill (1973, p. 16)
UH-1H	Laing and Hepler (1973, p. 16)

* Original data points are shown. We have added the connecting line segments as a visual aid only. They do not indicate continuous data.

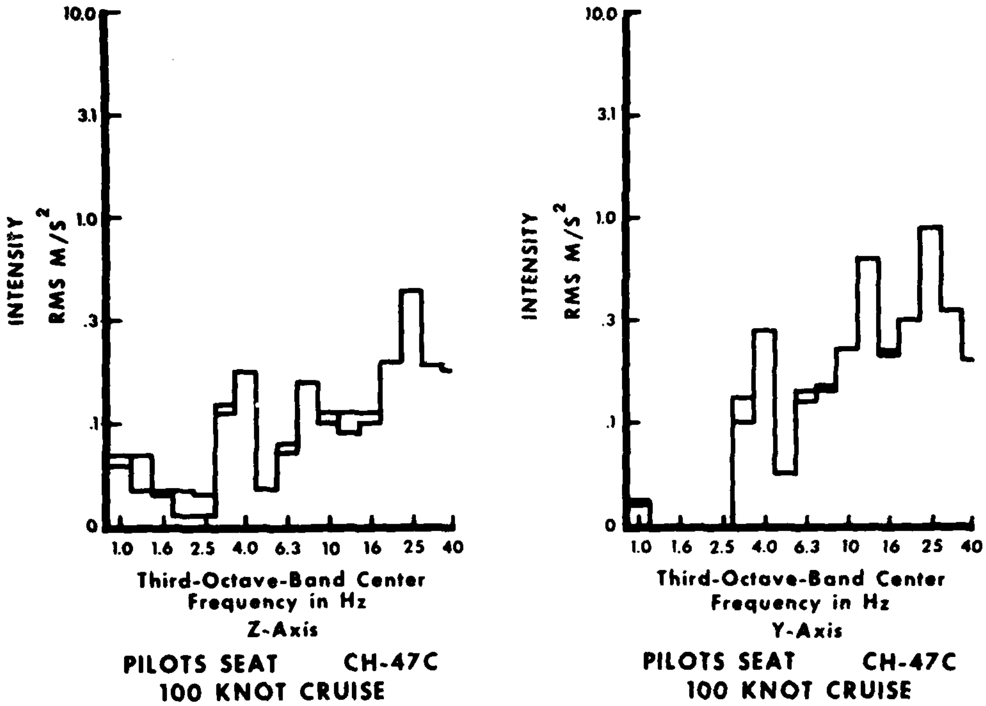

FIGURE 5. Pilot Seat Vibration in Z and Y Axes as Measured by Hutchins

CH-47C Pilots' Seat Z-Axis, Hutchins (1972, p. B1/51)
CH-47C Pilots' Seat Y-Axis, Hutchins (1972, p. B1/51)

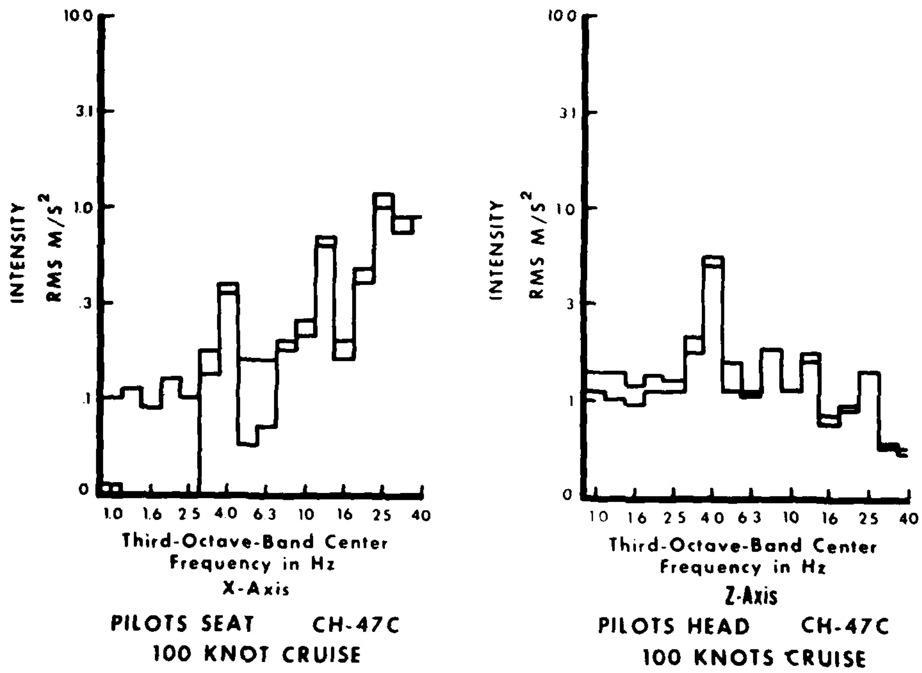

FIGURE 6. Pilot Seat Vibration (X Axis) and Head Vibration (Z Axis) as Measured by Hutchins

CH-47C Pilots' Seat X-Axis, Hutchins (1972, p. B1/51)
CH-47C Pilots' Head Z-Axis, Hutchins (1972, p. B5/55)

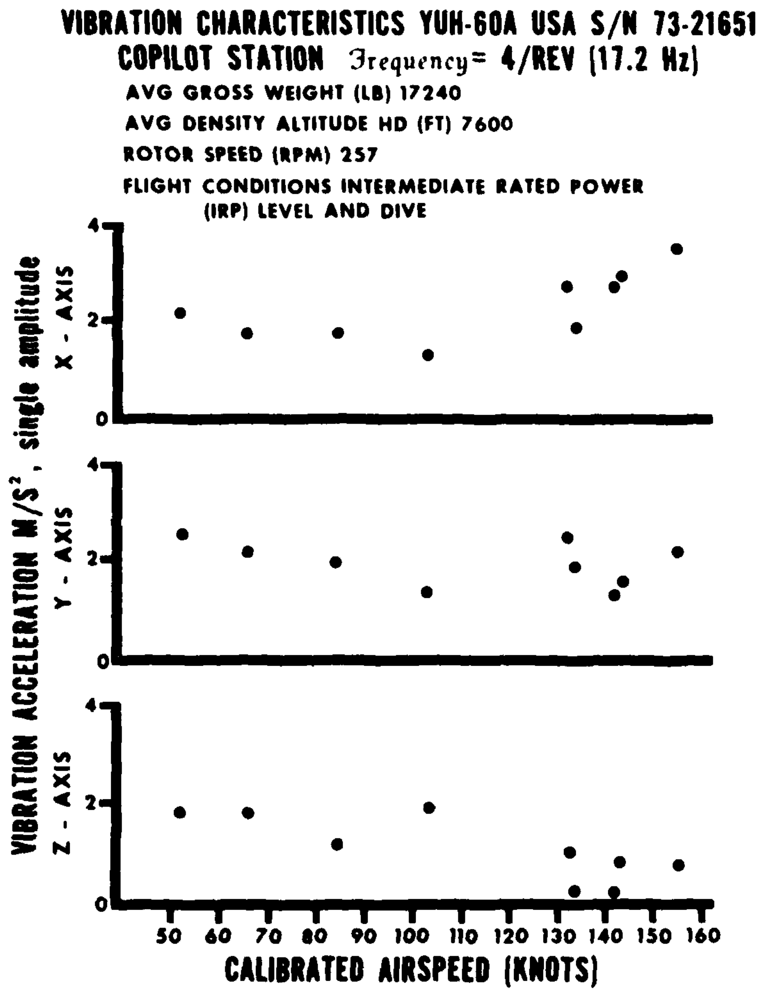

FIGURE 7. Vibration Levels at Copilot Station in a YUH-60A Utility Helicopter

Mittag (1976, p. 285)

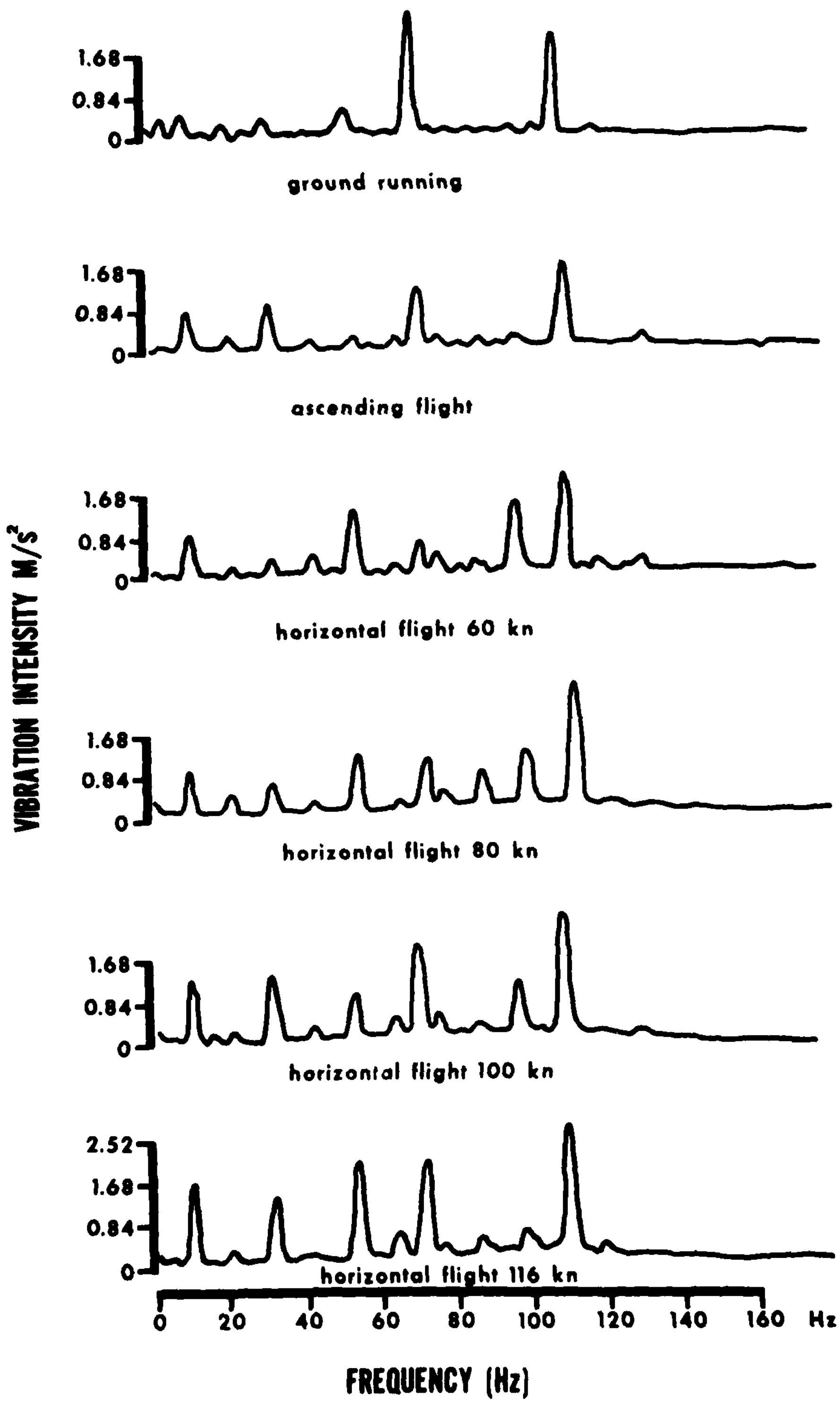

FIGURE 8. Vibration Levels at Stretcher Fastening Points in a UH-1H Helicopter Dupuis (1978, p. 12-9, 12-10)

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